UPDATED STANDARDIZED CATCH RATES FOR THE NORTH ATLANTIC STOCK OF SWORDFISH (*Xiphias gladius*) FROM THE SPANISH SURFACE LONGLINE FLEET FOR THE PERIOD 1986-2019

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SUMMARY

Log-normal Generalized Linear Models (GLM) were used to update the standardized catch rates (in weight and in number) of the Spanish surface longline fleet targeting swordfish during the period 1986-2019 in areas of the North Atlantic stock. Factors such as area, quarter, gear and bait as well as the fishing-targeting strategy - based on the ratio between the two most prevalent species and those most highly valued by skippers - were considered. The base case models explained 59% and 57% of CPUE variability in weight and in number of fish, respectively. The increases in relative abundance in number of fish and in weight between the lowest levels in record occurred during the mid nineties and the values reached in the last year considered in the present analyse were around +65%.

RÉSUMÉ

Des modèles linéaires généralisés log-normaux (GLM) ont été utilisés pour actualiser les taux de capture standardisés (en poids et en nombre) de la flottille palangrière de surface espagnole ciblant l'espadon au cours de la période 1986-2019 dans les zones du stock de l'Atlantique Nord. On a pris en compte des facteurs, tels que la zone, le trimestre, l'engin et l'appât ainsi que la stratégie de ciblage de pêche, sur la base du ratio entre les deux espèces les plus nombreuses et celles les plus prisées par les capitaines. Le cas de base des modèles expliquait 59% et 57% de la variabilité de la CPUE en poids et en nombre de poissons, respectivement. Les augmentations de l'abondance relative en nombre de poissons et en poids entre les niveaux les plus faibles enregistrés au milieu des années 1990 et les valeurs atteintes dans la dernière année étudiée dans la présente analyse se situaient à environ +65%.

RESUMEN

Se presentan tasas de captura estandarizadas (en peso y en número de peces) obtenidas para la flota española de palangre de superficie que captura pez espada en áreas del stock del Atlántico Norte para el período 1986-2019, aplicando Modelos Lineales Generalizados (GLM) con una aproximación log-normal similar a la usada en anteriores análisis. Se tuvieron en consideración los factores área, trimestre, arte, cebo así como la estrategia pesquera basándose en el ratio entre la captura de las dos especies más prevalentes y valoradas por los capitanes de pesca. Los modelos GLM caso básico explicaron el 59% y 57% de la variabilidad de la CPUE en peso y en número de peces, respectivamente. Los incrementos en abundancia relativa en número de peces y en peso entre los niveles más bajos registrados a mediados de los noventa y los valores alcanzados en el último año considerado en los presentes análisis, rondaron el + 65%.

KEYWORDS

Swordfish, CPUE, GLM, Abundance, Longline

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1. Introduction

Fishing for swordfish has been an activity cited by medieval and classical writers whose earliest known history dates back to the ancient cultures of the Mediterranean Sea. Rich (1947) summarized some quotes from classics from Greece and Rome that referred to fishing on this species (“Xiphonion”) at least 2400 years ago: "*the Romans carried out this type of fishing throughout the entire Mediterranean, from Byzantium to Gibraltar, which should indicate the importance of their fishing for the inhabitants of the coastal regions*". Aristotle originally named this species Xiphias, currently known as *Xiphias gladius* which was the name that Linnaeus gave this species at a later date. Fishing with lines and small longlines in the eastern Mediterranean Sea and in southern regions of Spain in their near-coastal Atlantic areas has been documented since at least the 19th century (Rodríguez-Santamaría 1923) although initially the fishing activity was probably targeting other fish species (Rey *et al.* 1988).

The main recent development and geographical expansion of the Spanish ocean-going night setting longline fishery targeting swordfish in the North Atlantic stock dates from the early 1980s. After that time scientific tracking systems were introduced and those have continued up to the present. A detailed description of changes over time in this fishery was provided in previous SCRS papers (e.g. Mejuto *et al*. 1997, 1998, 1999b, 2000, 2001, 2002; Mejuto and De la Serna 1995, 1997, 2000) and in other sources (e.g. Mejuto 2007). In summary, the gear configuration of the Spanish surface longline fleet targeting swordfish in the North Atlantic was relatively stable during several decades of the past century when the multifilament-traditional style was used, but an important change occurred around the end of the past century when the multifilament style was swiftly replaced by the American-style monofilament (García-Cortés *et al.* 2010, Mejuto *et al*. 2011). On-board freezing systems were gradually introduced from the mid-1980s onwards and this, together with other factors such a quota allocation and changes in markets, allowed and encouraged skippers to retain and land any blue shark they caught, leading to a gradual change in the fishing strategy of the North Atlantic fleet as previously described. Initially swordfish was the main species targeted but the fishing strategy progressively became broader, targeting either of these two abundant species (swordfish and blue shark). All these changes over time have had an important impact on the nominal CPUE observed and they were studied and considered in previous descriptions and standardized CPUE analyses (e.g. Mejuto and De la Serna 2000, Anon. 2001, Ortiz and Scott 2003, Mejuto 2007, Ortiz *et al.* 2010, García-Cortés *et al.* 2017). However, since the most recent swordfish assessment of the Northern stock there have been no substantial changes in this fishery other than those involving regulatory measures introduced at a national level. The gear style, fishing areas and fishing strategy in recent years has remained.

Full stock assessments commonly require among other information “*indices of relative abundance*” that should be standardized (Maunder and Punt 2004, Maunder *et al.* 2006). The catches per unit of effort (CPUE) could be in some cases assumed to be reliable indicators of the relative abundance for large pelagic fish in view of the lack of direct abundance indicators or independent fishery data. But CPUE indicators must be evaluated on a case-by-case basis taking into account -among other diagnoses- the history and empirical knowledge of each fishery, the quality and quantity of the data used, the spatial coverage of the data in relation to the total stock distribution, the stability in the areas-times of the fishing over time, as well as the biological plausibility of the inter-annual CPUE variability obtained. The most common method for standardizing CPUE is the application of generalized linear models (GLM) (Robson 1966, Gavaris 1980, Kimura 1981), which removes the effect of factors that bias the index. Indirect factors such as operational changes over time, technological advances, changes in the target species and their respective fishing areas over time, or in some cases the leader-branch lines and hook-bait types or even the criteria of the skippers, among others, could be good alternatives to be explored for the CPUE standardizations and their interpretations. Special caution should be considered in the case of fleets that have changed their target species over time from a temperate to a tropical species and/or their fishing gear-style accompanied by drastic shifts of fishing areas. In such cases, the increase in CPUE of the new targeted species may lead to a decrease in the CPUE of the old targeted or bycatch species due to different primary areas of their distributions and distinct environmental preferences. In such cases, even a standardized CPUE could have difficulties in considering a constant catchability coefficient and those CPUEs as indicators of relative abundance of the stock through the complete time series.

The standardized catch rates of the Atlantic swordfish and other large pelagic species were obtained in recent decades by means of GLM from a number of commercial longline fleets taking into consideration those factors affecting each fleet and species (e.g. Anon. 1989, 1991; Hoey *et al*. 1989, 1993; Nakano 1993, Mejuto 1993, 1994; Scott *et al*. 1993, Mejuto and De la Serna 1995, Mejuto *et al*. 1999a, 2003; Ortiz *et al*. 2007, Babcock and Skomal 2008, Brown 2008, Cortés 2008, 2009, 2010; Fowler and Campana 2009, Matsunaga 2008, Mourato *et al.* 2007, 2008; Pons and Domingo 2008, García-Cortés *et al*. 2014, 2017; Ramos-Cartelle *et al*. 2014, 2017).

The aim of this document is to update standardized CPUE series previously provided for the assessment of the North Atlantic swordfish stock but in this case covering a 34-year period of scientific data, in a bid to be consistent with those approaches previously presented and assumed for the assessments of the North Atlantic stock.

2. Material and methods

Data records per trip from the period 1986-2019 were scientifically recorded mostly during the landing of fish by the Spanish North Atlantic fleet. Other sources of complementary information such as interviews, some scientific observers at sea and trip-logbook data were also used. More details about methodology can be found in previous papers (e.g. Mejuto and De la Serna 2000, Mejuto *et al.* 2000, 2001 and 2002). Base case analyses of standardized log-normal CPUE (GLM) using *SAS 9.4* were performed to be compared with previous analyses (García-Cortés *et al.* 2017) and an alternative-sensitivity procedure (MIXED) was also implemented.

GLM: $Ln\ (CPUE) = u + Y + Q + A + R + G + B + A*Q + e$
MIXED: $Ln\ (CPUE) = u + Y + A + R + G + Q + A*R + e + random\ (Y*A + Y*R)$

where: u = overall mean, Y = *year* effect, Q = *quarter* effect (Q1 = January- March; Q2 = April-June; Q3 = July-September; Q4 = October-December), A = *area* effect (**Figure 1**), R = *ratio* effect (defined for each available trip record as an indicator of the target criteria of the skipper expressed as the percentage of swordfish by weight related to the catches in weight of swordfish and blue shark combined, classified in ten categories at 10% intervals) (Mejuto and De la Serna 2000), G = *gear* effect (1: traditional multifilament, 3:American-style monofilament, 9: unknown), B= *bait* type (1 = mackerel, 6 = squid and 9 = other types or combinations) and e = logarithm of the normally distributed error term. The symbol * represents the interactions between factors.

In base case runs, the response variable - CPUE - was measured in kg round weight and in number of fish per fishing effort (thousands of hooks). Standardized residuals by year were plotted to evaluate the extent of serial autocorrelation in the residuals. The standardized mean weight by year and the confidence intervals were also obtained using the same GLM approach.

The alternative-sensitivity MIXED procedure was performed measuring the CPUE in kg round weight. The standardized CPUE in weight obtained from the sensitivity analysis was scaled in order to compare it with the scaled standardized CPUE in weight obtained by the base case GLM run. Both series were scaled to their respective mean values.

3. Results and discussion

Figure 1 shows geographical area defined for the GLM runs for the period analyzed (1986-2019) and a summary of the area-coverage (5ºx5º) of the information. A total number of 15,131 trip observations were available, equivalent to 527.5 x 10^6 hooks observed. The combined information covers around 60% of the 5ºx5º squares of the North stock distribution (considering restricted areas between 5º-50ºN) and most of those temperate Eastern and central North Atlantic squares where swordfish is regularly distributed.

A summary of the ANOVA results from the base case GLM procedures is shown in **Table 1**. 59% and 57% of CPUE variability in weight and number, respectively, was explained by the significant models defined. CPUE variability (Type III SS) could be mostly explained by the targeting or type of trip (*ratio* effect) which was significant, as in previous analyses. The impact of certain changes in the fishing strategy over time of the Spanish fleet has already been described and assessed in other papers, compared with the results obtained using other possible approaches (Mejuto and De la Serna 2000, Mejuto *et al*. 2000) and it was assessed by the method's working group of ICCAT (Anon. 2001). Other factors were important in CPUE variability but as regards CPUE in weight rather than in the number of fish. The *quarter*, *gear* and *year* factors were quite important in the variability of CPUE in weight, but the *area* factor was in the variability of CPUE in number.

Figure 2 shows the frequency distribution of standardized residuals and normal probability qq-plot in weight and in number of fish. **Figures 3** and **4** show the variability box-plot for standardized residuals obtained by the main factors considered in the base case runs. **Tables 2** and **3** provide information on estimated lsmean parameters, their standard error, CV%, standard CPUE and upper and lower 95% confidence limits, in weight and in number, respectively. **Figure 5** shows the base case standardized CPUE in weight and number as well as the standardized mean weight obtained by year and their respective 95% confidence intervals.
The results confirm the same patterns obtained in recent analyses. The indices of relative abundance show an

overall slight decrease in number and weight up to the mid nineties, followed by a change of phase and a clear upper trend after that period due to regulations implemented and/or the more positive recruitment scenario which occurred after 1996 probably related to a more favourable environmental phase described by other authors. These positive effects were progressively incorporated in the respective year-classes and revealed in the abundance of ages combined over time of this fleet. The increase in relative abundance in number of fish and in weight between the lowest levels occurred during the mid nineties and the values reached in the last year considered in the present analyses (2019) were around +65%. A similar conclusion can be reached when the standardized mean weight trend for the period up to 1999 is observed and the increased trend after that year. The results would suggest that during the current century the biomass of the North Atlantic swordfish has had an overall stable or slightly upward trend and current levels are well above those observed at the end of the past century.

It is probably important to note that these indices included all sizes-ages combined (see previous references) caught by this longline fleet. Consequently, retained catches of ages one and two –although relatively minor in number and even lesser in total biomass- are also incorporated in the present and in previous analyses as also reported in CAS data. Any comparison of these results with CPUE indices obtained for other fleets should take into account the respective size-age-fractions considered in each case-data, the respective minimum size regulations implemented by each fleet and the reporting rates of such fishes in mandatory systems. Small fish can be a quite important fraction of the catches in some fleets-areas fishing in warm waters where juveniles may be very abundant or even the most prevalent fraction in some cases-areas.

The result obtained from the MIXED model was very similar to the base case GLM model. A comparison of the two scaled standardized CPUEs obtained in weight showed a very similar general trend over time, regardless of the model used (**Figure 6**). However, the mixed model shows a slightly more optimistic trend than the base case model for the most recent years. The updated index is very consistent with that given in 2017 (García-Cortés and *al.* 2017).

Acknowledgments

The authors would like to give their warmest thanks to all the members of the team who were involved in recording, recovering, preparing and processing the basic data. We would also like to thank the skippers of the Spanish longline fleet for their voluntary assistance with this long-term scientific effort maintained over 34 years.

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Table 1. Summary of ANOVAs for each CPUE analysis, in weight (upper table) and in number (lower table).

North Atl. CPUE in weight (kg RW)
Dependent variable: ln (CPUEw)

Source	DF	Sum of Squares	Mean Square	F Value	Pr > F
Model	64	4701.204537	73.456321	339.84	<.0001
Error	15066	3256.536150	0.216151		
Corrected Total	15130	7957.740688			

R-Square	Coeff. Var.	Root MSE	cpue Mean
0.590771	8.509438	0.464921	5.46359

Source	DF	Type III SS	Mean Square	F Value	Pr > F
year	33	144.493870	4.378602	20.26	<.0001
quarter	3	146.182211	48.727404	225.43	<.0001
area	4	96.758290	24.189573	111.91	<.0001
gear	1	142.078592	142.078592	657.31	<.0001
bait	2	15.044128	7.522064	34.80	<.0001
ratio	9	1780.234352	197.803817	915.12	<.0001
quarter*area	12	77.107843	6.425654	29.73	<.0001

North Atl. CPUE in number of fish
Dependent variable: ln (CPUEn)

Source	DF	Sum of Squares	Mean Square	F Value	Pr > F
Model	64	4890.750771	76.417981	307.16	<.0001
Error	15066	3748.234454	0.248788		
Corrected Total	15130	8638.985226			

R-Square	Coeff. Var.	Root MSE	cpue Mean
0.566126	27.66542	0.498786	1.802923

Source	DF	Type III SS	Mean Square	F Value	Pr > F
year	33	139.587110	4.229912	17.00	<.0001
quarter	3	105.494244	35.164748	141.34	<.0001
area	4	281.077358	70.269339	282.45	<.0001
gear	1	176.022109	176.022109	707.52	<.0001
bait	2	13.669246	6.834623	27.47	<.0001
ratio	9	1712.773569	190.308174	764.94	<.0001
quarter*area	12	51.847711	4.320643	17.37	<.0001

Table 2. Estimated parameters (Lsmean), standard error (Stderr), CV%, relative mean CPUE in weight-kg RW- (CPUEw) of swordfish and upper and lower 95% confidence limits, for the Spanish longline fleet in the North Atlantic during the period analyzed (1986-2019).

Yr	Lsmean	Stderr	CV%	CPUEw	95%UCPUEw	95%LCPUEw
1986	5.53385	0.024678	0.4459	253.193	265.740	241.237
1987	5.61197	0.029897	0.5327	273.806	290.330	258.222
1988	5.48055	0.030201	0.5511	240.088	254.729	226.289
1989	5.50208	0.027850	0.5062	245.296	259.058	232.266
1990	5.48137	0.025991	0.4742	240.257	252.814	228.324
1991	5.50448	0.026222	0.4764	245.875	258.842	233.557
1992	5.49344	0.026473	0.4819	243.178	256.129	230.882
1993	5.36430	0.027104	0.5053	213.719	225.380	202.662
1994	5.33860	0.024864	0.4657	208.285	218.687	198.378
1995	5.44982	0.023440	0.4301	232.781	243.725	222.328
1996	5.29094	0.022694	0.4289	198.582	207.614	189.942
1997	5.30636	0.022115	0.4168	201.665	210.598	193.110
1998	5.34601	0.021030	0.3934	209.816	218.645	201.343
1999	5.42869	0.022050	0.4062	227.905	237.971	218.266
2000	5.74611	0.020300	0.3533	313.035	325.741	300.825
2001	5.67285	0.021273	0.3750	290.929	303.316	279.049
2002	5.61370	0.022766	0.4055	274.227	286.741	262.259
2003	5.64358	0.024781	0.4391	282.560	296.623	269.164
2004	5.65995	0.025225	0.4457	287.224	301.782	273.369
2005	5.65773	0.026164	0.4624	286.596	301.676	272.269
2006	5.56481	0.029612	0.5321	261.191	276.799	246.463
2007	5.71559	0.029698	0.5196	303.696	321.898	286.523
2008	5.85008	0.029041	0.4964	347.409	367.757	328.187
2009	5.74639	0.027805	0.4839	313.178	330.719	296.567
2010	5.74348	0.027719	0.4826	312.269	329.704	295.757
2011	5.80724	0.028141	0.4846	332.831	351.705	314.971
2012	5.82315	0.027980	0.4805	338.169	357.233	320.123
2013	5.81827	0.029417	0.5056	336.536	356.509	317.681
2014	5.78495	0.029844	0.5159	325.510	345.119	307.016
2015	5.77776	0.029605	0.5124	323.177	342.484	304.958
2016	5.87760	0.035428	0.6028	357.174	382.857	333.214
2017	5.78402	0.036502	0.6311	325.279	349.404	302.821
2018	5.75878	0.038164	0.6627	317.192	341.828	294.331
2019	5.76214	0.036871	0.6399	318.244	342.094	296.057

Table 3. Estimated parameters (Lsmean), standard error (Stderr), CV%, relative mean CPUE in number of swordfish (CPUEn) and upper and lower 95% confidence limits, for the Spanish longline fleet in the North Atlantic during the period analyzed (1986-2019).

Yr	Lsmean	Stderr	CV%	CPUEn	95%UCPUEn	95%LCPUEn
1986	1.68796	0.02648	1.5685	5.410	5.699	5.137
1987	1.83357	0.03208	1.7493	6.259	6.666	5.878
1988	1.75542	0.03240	1.8458	5.789	6.168	5.433
1989	1.76669	0.02988	1.6912	5.854	6.207	5.521
1990	1.76549	0.02789	1.5794	5.847	6.175	5.536
1991	1.68529	0.02813	1.6693	5.396	5.702	5.107
1992	1.68497	0.02840	1.6856	5.394	5.703	5.102
1993	1.57410	0.02908	1.8473	4.828	5.112	4.561
1994	1.58869	0.02668	1.6791	4.899	5.162	4.650
1995	1.75452	0.02515	1.4333	5.782	6.075	5.504
1996	1.65027	0.02435	1.4753	5.210	5.465	4.967
1997	1.79218	0.02373	1.3239	6.004	6.290	5.731
1998	1.82486	0.02256	1.2364	6.203	6.484	5.935
1999	1.92634	0.02366	1.2280	6.866	7.192	6.555
2000	2.13504	0.02178	1.0200	8.459	8.828	8.106
2001	2.04392	0.02282	1.1166	7.723	8.076	7.385
2002	1.96967	0.02443	1.2401	7.170	7.522	6.835
2003	1.98981	0.02659	1.3362	7.317	7.708	6.945
2004	2.00079	0.02706	1.3526	7.398	7.801	7.015
2005	2.05852	0.02807	1.3636	7.837	8.281	7.418
2006	2.01303	0.03177	1.5782	7.490	7.971	7.038
2007	2.13536	0.03186	1.4921	8.464	9.010	7.952
2008	2.21641	0.03116	1.4057	9.179	9.757	8.635
2009	2.06214	0.02983	1.4466	7.866	8.340	7.420
2010	2.10812	0.02974	1.4106	8.236	8.731	7.770
2011	2.10654	0.03019	1.4332	8.224	8.725	7.751
2012	2.11731	0.03002	1.4178	8.312	8.816	7.838
2013	2.08090	0.03156	1.5166	8.016	8.527	7.535
2014	2.03624	0.03202	1.5724	7.666	8.162	7.199
2015	2.02472	0.03176	1.5687	7.578	8.065	7.120
2016	2.11951	0.03801	1.7932	8.333	8.978	7.735
2017	2.03193	0.03916	1.9273	7.635	8.244	7.071
2018	2.05603	0.04094	1.9914	7.821	8.475	7.218
2019	2.04538	0.03956	1.9340	7.738	8.362	7.161

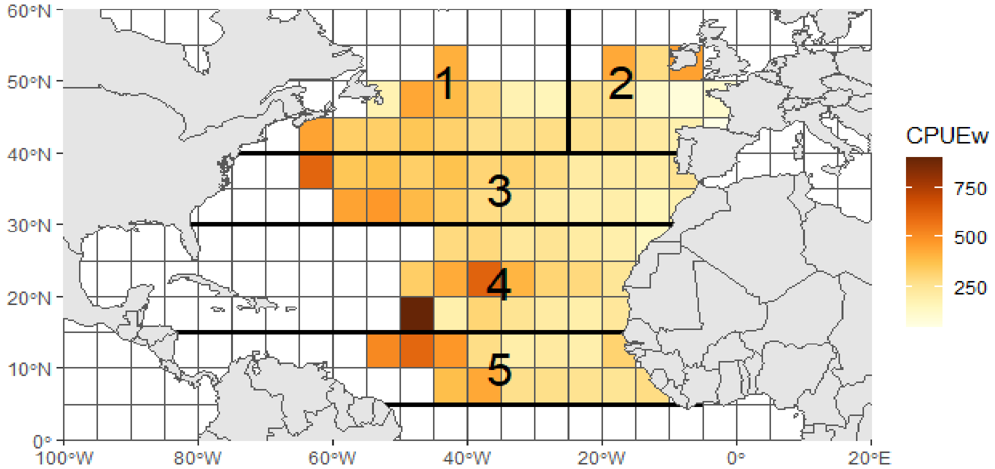

Figure 1. Geographical area definition used in GLM runs for the CPUE standardization of the Spanish surface longline fleet in the North Atlantic stock during the period 1986-2019. Scale color represents a summary of the squares observed over time and the observed nominal CPUEw (kg RW/1000 hooks) per 5ºx5º square years combined.

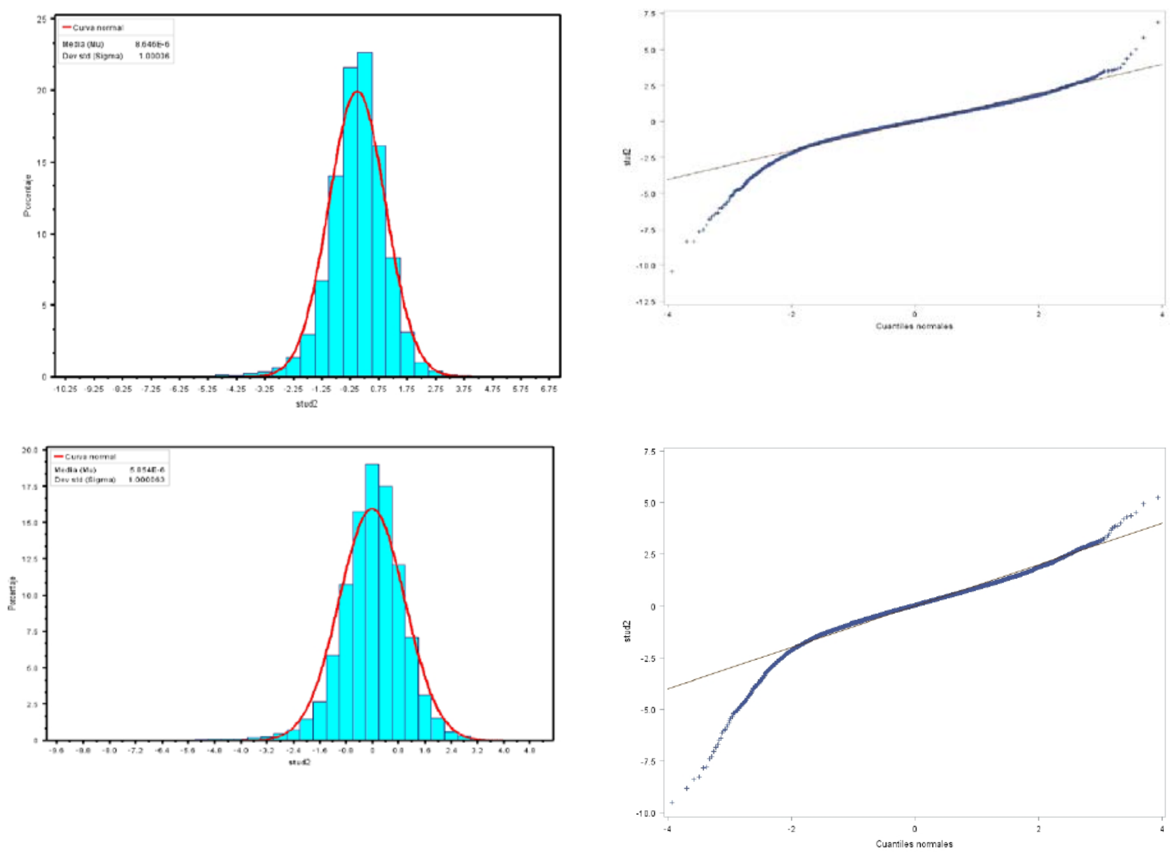

Figure 2. Frequency distribution of standardized residuals, years combined, and normal probability qq-plot; in weight (upper panels) and in number of fish (lower panels).

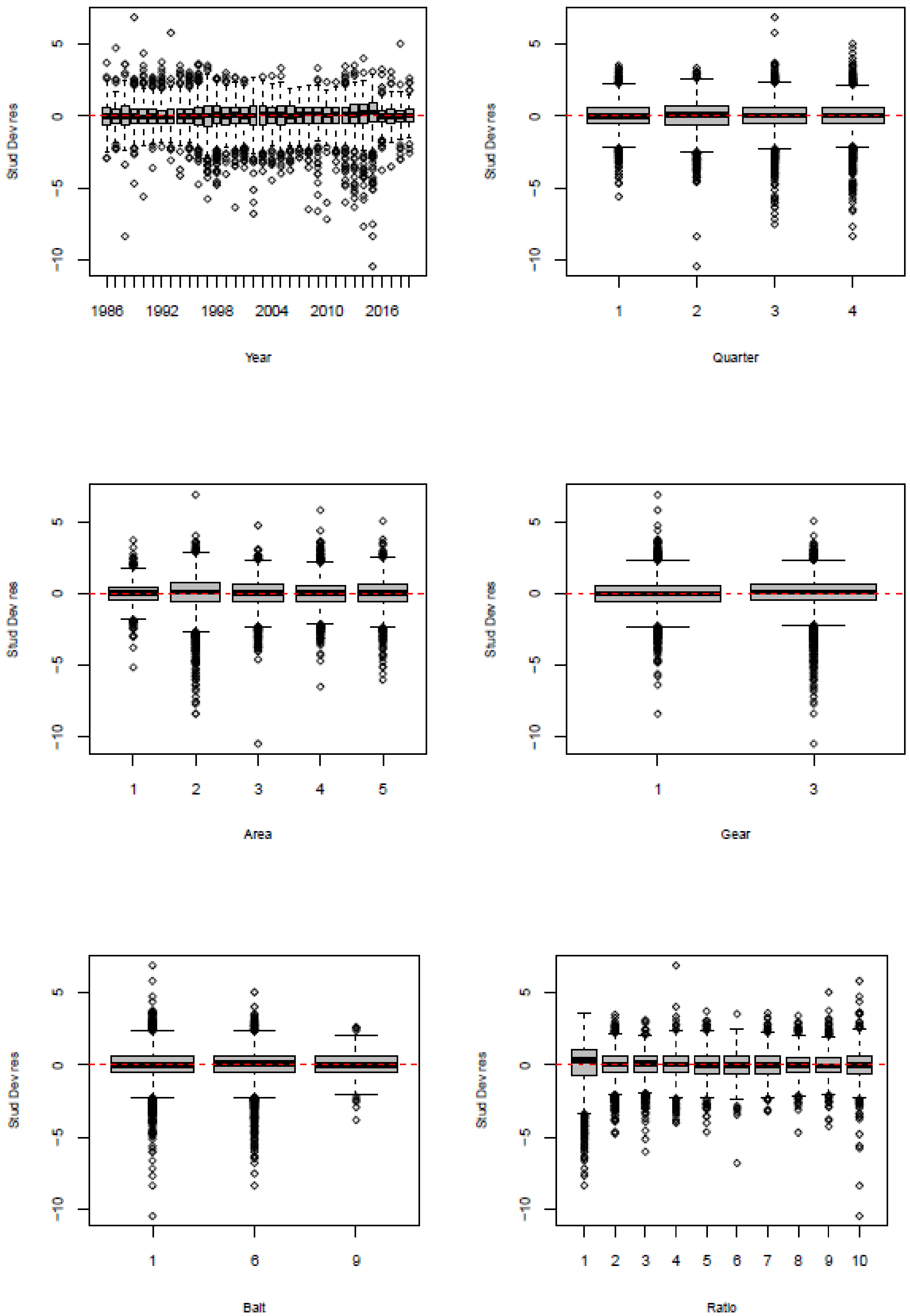

Figure 3. Box-plots of the standardized deviance residuals by explanatory variables obtained from the GLM base case in weight for the North Atlantic stock.

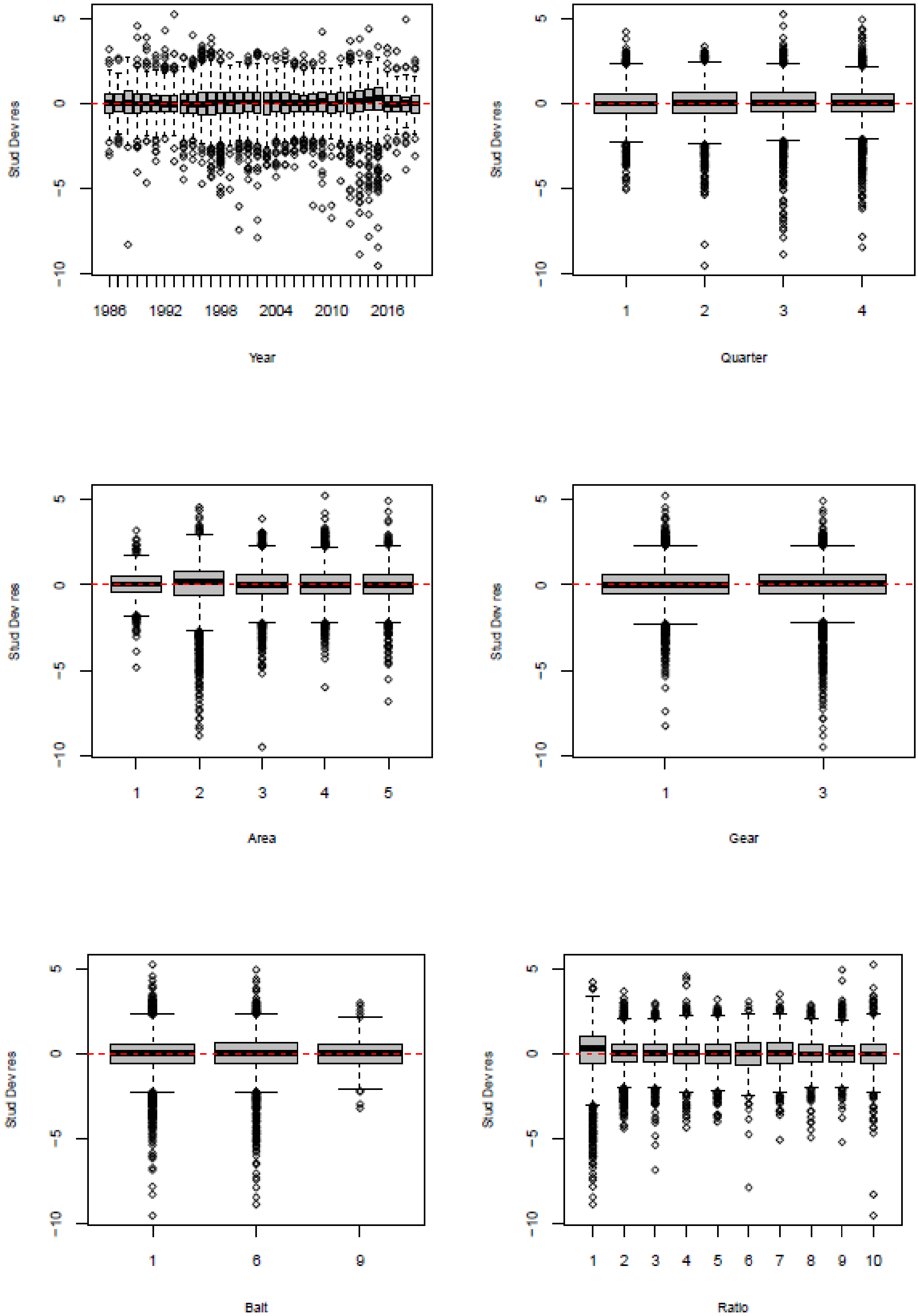

Figure 4. Box-plots of standardized deviance residuals by explanatory variables obtained from the GLM base case in number of fish for the North Atlantic stock.

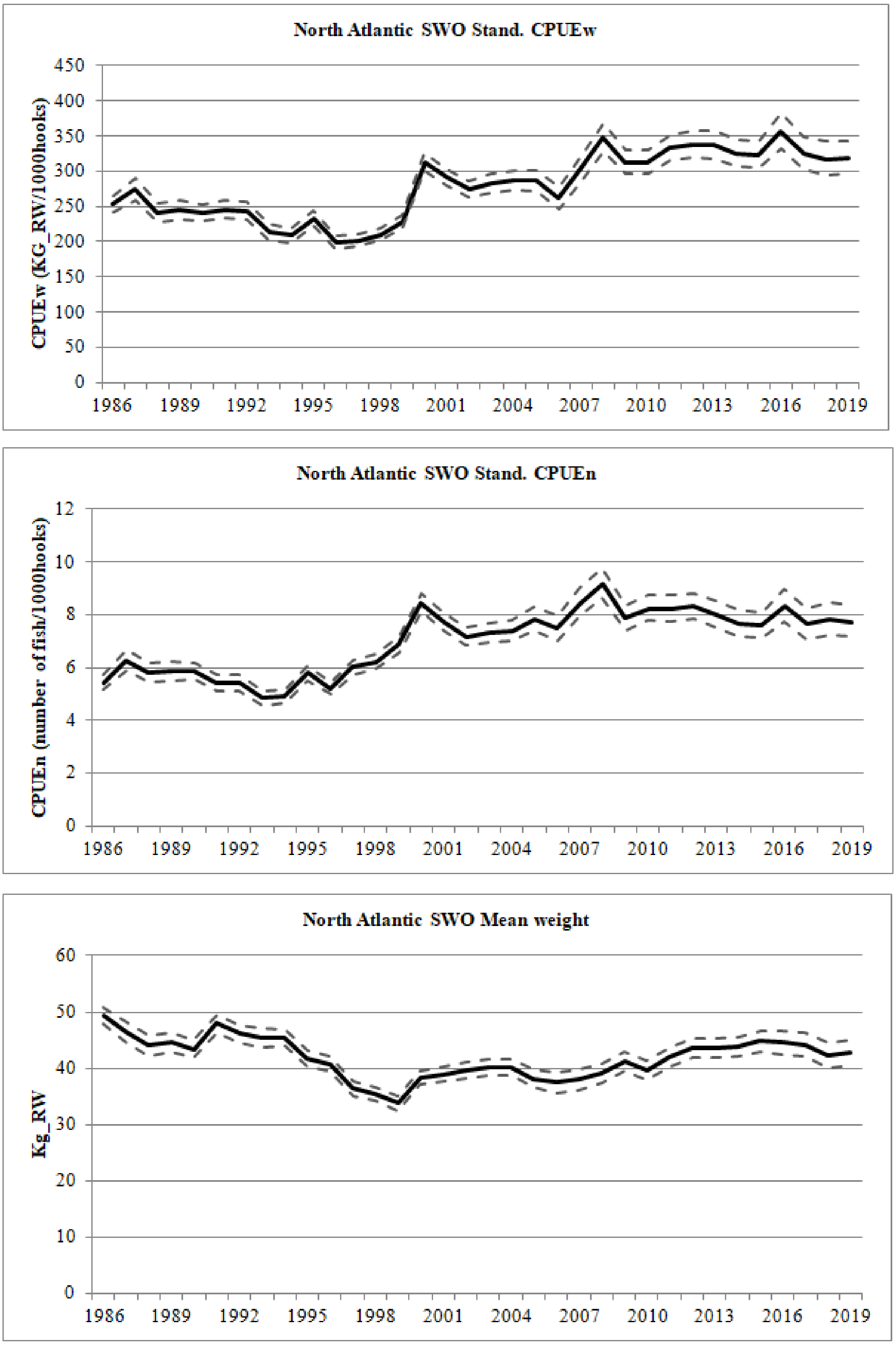

Figure 5. Standardized CPUEs per thousand hooks, in kilograms round weight (upper), in number of swordfish (middle) and standardized mean round weight in kilograms (lower) of swordfish and their respective confidence intervals (95%), observed in the Spanish surface longline fleet in the North Atlantic stock during the period analyzed (1986-2019).

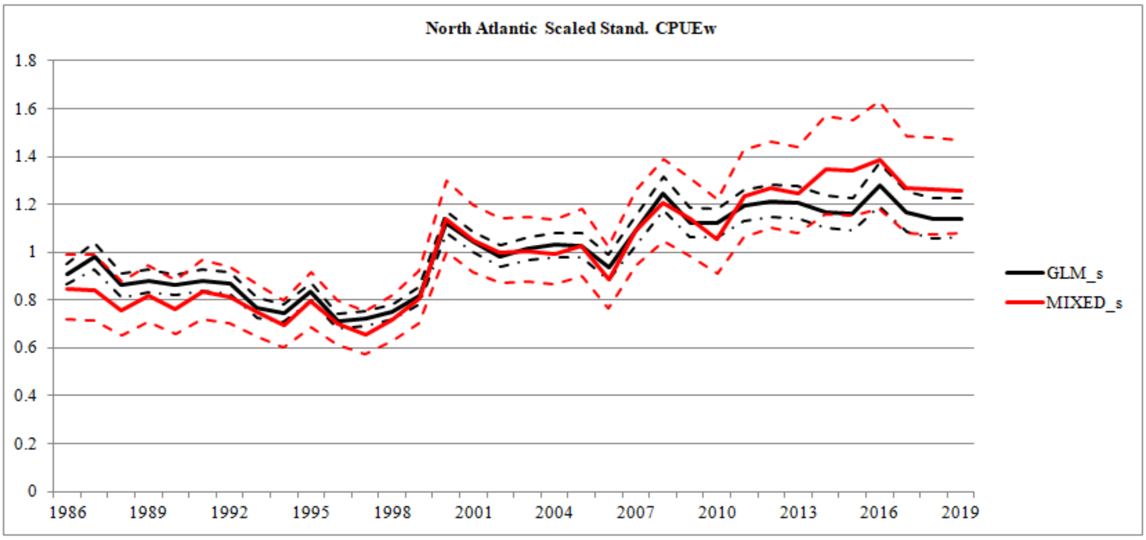

Figure 6. Comparative scaled standardized CPUE of swordfish (in kg round weight per thousand hooks) GLM *versus* MIXED procedure in the North Atlantic stock for the period 1986-2019. Both series are scaled from their respective mean value.